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Patellar instability: CT and MRI measurements and their correlation with internal derangement findings

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Abstract

Purpose To test the inter-observer and inter-method reliability among the measures suggesting patellofemoral joint disorder on both CT and MRI in the same subject and find possible association with internal derangements of the patellofemoral joint on MRI.

Methods Institutional review board approval was obtained with waiver of the informed consent in this HIPPA-compliant study. CT and MRI were evaluated in 32 knees in 32 respective subjects (10 men/22 women, mean age 38 ± 19 years). Three trained observers assessed tibial tuberosity–trochlear groove (TT–TG) distance, trochlear angle and trochlear depth on both CT and MRI. Intra-class correlation coefficient (ICC) was used to evaluate inter-observer and inter-method reliability. Two radiologists' consensus reading was used to evaluate their association with soft tissue abnormalities of the patellofemoral joint. Chi-square test was used to assess the statistical significance of the qualitative variables.

Results There was an excellent inter-observer reliability (ICC for CT >0.89 and for MRI >0.90) and inter-method reliability (ICC >0.86) for all the quantitative measurements. There was a significant association between increased TT–TG distance value on MR imaging and lateral facet patellar cartilage abnormality and joint effusion ($p < 0.05$).

Conclusion Quantitative trochlear parameters can be reliably calculated on MRI, and an abnormal TT–TG distance is the most useful measurement among various static MR imaging parameters to correlate with patellar chondrosis and joint effusion. TT–TG distance should be reported in patellofemoral pain syndrome patients.

Level of evidence IV.

Keywords Patellofemoral disorder · Tibial tuberosity–trochlear groove distance · TT–TG · Trochlear dysplasia · Patella maltracking

Introduction

Patellofemoral pain syndrome is a common problem in young patients leading to significant internal derangement and early osteoarthritis [9, 10]. The aetiologies of patellofemoral disorders may be intra-articular (trochlear dysplasia, patellar dysplasia), periarticular (hypoplasia of vastus medialis, patella alta, increased external rotation of the proximal tibia with lateralization of the patellar tendon insertion) and extraarticular (increased valgus positioning of the distal femur, sometimes in combination with genu recurvatum and increased anterior torsion of the femoral neck) [1–3, 19, 26, 33]. Patellofemoral disorders due to patellar instability or malalignment commonly cause anterior knee pain and patellofemoral chondrosis [16, 27].

Anatomical features associated with these disorders and features of joint degeneration or prior trauma can be identified clinically and radiologically [14]. One clinical measure used to evaluate patellar instability is the quadriceps angle (*Q* angle), first described by Brattstörm [5]. It

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has been suggested that an increased *Q* angle (>20°) is associated with an increased risk of anterior knee pain and patellar instability [29]. However, there is some disagreement on the reliability and validity of the *Q* angle. It can be affected by the anatomical points as well as altered by patient position, rotation of the limb, degree of knee flexion and whether the quadriceps are relaxed or contracted [17, 18]. Hence, it cannot be used as an optimal tool to diagnose patellar instability. The tibial tuberosity–trochlear groove (TT–TG) distance is, however, a surrogate marker of the *Q* angle and can be measured on cross-sectional imaging. The Norwich patellar instability (NPI) score has recently been shown to be a valid clinical tool to assess patellar instability for individuals following patellar dislocation; however, it requires further studies to prove its reliability [28].

Various other measurements have also been proposed on computed tomography (CT) and magnetic resonance imaging (MRI) to correlate with patellar malalignment/maltracking. According to Dejour et al. [11], relevant factors associated with patellar instability are trochlear dysplasia, quadriceps dysplasia, patella alta and TT–TG distance. Patellar position and alignment varies on static CT/MR imaging. However, TT–TG distance, trochlear angle (TA) and trochlear depth (TD) are relatively stable measurements and are most commonly used by referring physicians to determine the treatment options [7, 8, 12, 21].

MRI may be used to measure the osseous and soft tissue abnormality indices responsible for patellofemoral disorders/instability and detection of internal derangement findings [6]. Also, due to radiation concerns in CT examinations, MRI would be the preferred modality for such measurements. The aims of this study were to test the interobserver and inter-method reliability of the above measures on CT and MRI and to correlate them with internal derangements of the patellofemoral joint on MRI.

Methods

This study was approved by the institutional review board, which allowed retrospective review of images and relevant records with waiver of the informed consent. Health Insurance Portability and Accountability Act (HIPPA) compliance was followed. Our radiology database was retrospectively reviewed for CT scans and MRI of knee from September 2008 to February 2011. Inclusion criteria were the following: patients should have undergone both CT scan and MRI of the same knee joint and should not have history of prior knee surgery. This search yielded a total of 32 patients (22 females and 10 males; age range 13–75 years, mean age 38 ± 19 years) having CT scan and MRI of 32 knees (12 right knees and 20 left knees). All the CT and MRI scans were obtained in the supine position with knee in the neutral position without any flexion. All patients were referred for imaging due to clinical history of possible underlying knee derangement, such as ligament injury, effusion or osteonecrosis, pre-operative evaluation for tumour, acute injury from motor vehicle accident or fall and osteoarthritis.

Fig. 1 Axial section of knee joint on CT (**a**) and non-fat-suppressed ▶ proton density MRI (**b**) showing the tibial tuberosity–trochlear groove distance measurement. TT–TG distance was measured from the deepest point of trochlear sulcus to the midpoint of the patella tendon at its insertion site on the tibial tuberosity

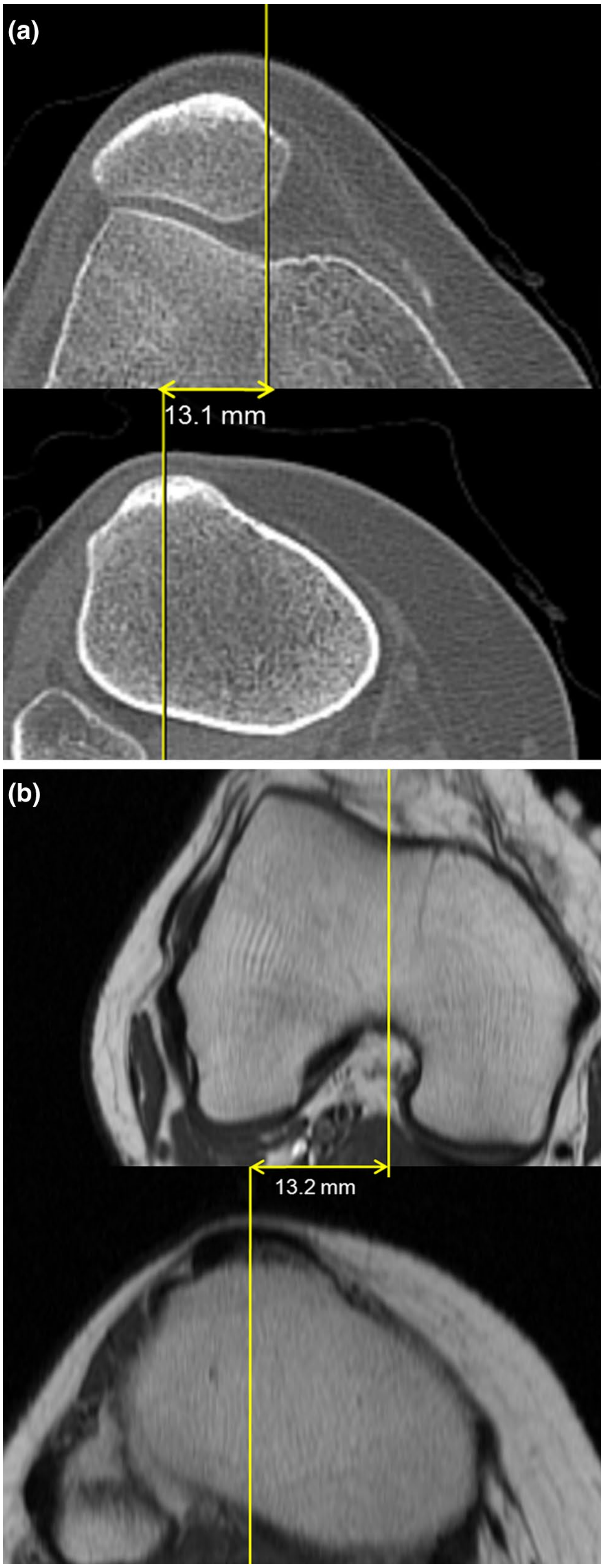
Image acquisition

Multislice CT examinations of the knee were performed, and the scans were uniformly reconstructed in 3-mm axial sections to measure TT–TG distance, TA and TD. Knee MRI were obtained on a variety of scanners, ranging from 1 to 3 Tesla, as the images were evaluated from various performance sites. However, all sites had axial non-fat-saturated T1-weighted (TR/TE—500–700/8–12 ms) or non-fat-saturated proton density sequence (TR/TE—1200–2000/20–40 ms), which were used to measure all the quantitative parameters of the trochlea. The thickness of MRI axial scans was at 4 mm. Qualitative soft tissue parameters were assessed using non-fat-suppressed and fat-suppressed proton density axial and sagittal sequences.

Image interpretation

All the quantitative and qualitative assessment of CT and MRI scans was done on our PACS workstation (UV; Emageon, Birmingham, AL, USA).

First, three independent examiners (R.T, F.D.G. and M.C. with 5-, 15- and 2-year radiology experience, respectively) performed the quantitative measurements of the trochlear parameters (TT–TG distance, TA and TD) on CT and MR images, separately. The readers were blinded to the measurements derived from each of the methods as well as each other's measurements. The physeal scar of the lateral femoral condyle was used as a reference point to measure all the quantitative measurements on both CT and MR scans. TT–TG distance was measured similar to the method proposed by Wittstein et al. [32] and measured from the deepest point of trochlear sulcus to the midpoint of the patella tendon at its insertion site on the tibial tuberosity. TA was calculated on axial scans on both CT and MRI as the angle between the medial and lateral trochlear facets. TD was calculated on axial scans on both CT and MRI as the perpendicular distance between the deepest point on the trochlear sulcus and the line joining the superior point of medial and lateral trochlear facets (Figs. 1, 2, 3).



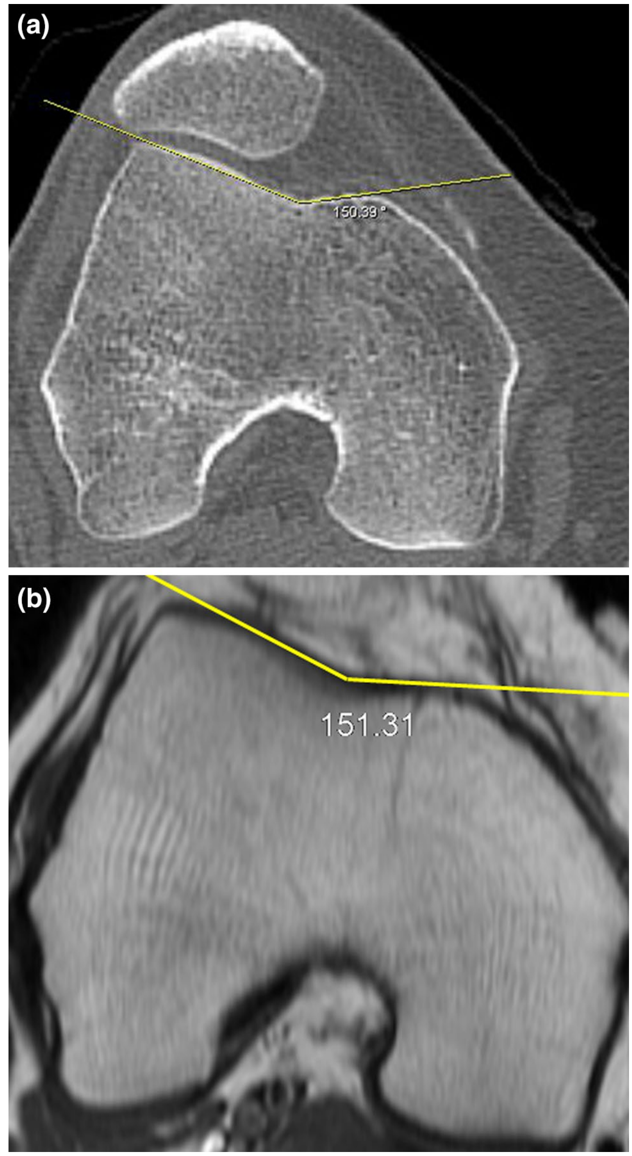


Fig. 2 Axial section of knee joint on CT (**a**) and non-fat-suppressed proton density MRI (**b**) showing the trochlear angle measurement. TA was calculated on axial scans on both CT and MRI as the angle between the medial and lateral trochlear facets

Second, two examiners (R.T and F.D.G.) assessed the qualitative soft tissue parameters such as joint effusion, fat pad oedema (quadriceps, pre-femoral and Hoffa's), patella and quadriceps tendon signal intensities, retinaculum thickness, retinaculum tear, patellar and trochlear bone marrow oedema, patellar and trochlear cyst formation, cartilage abnormality of patella and trochlea in consensus on the MR scans. Each of the soft tissue findings was scored 0 or 1

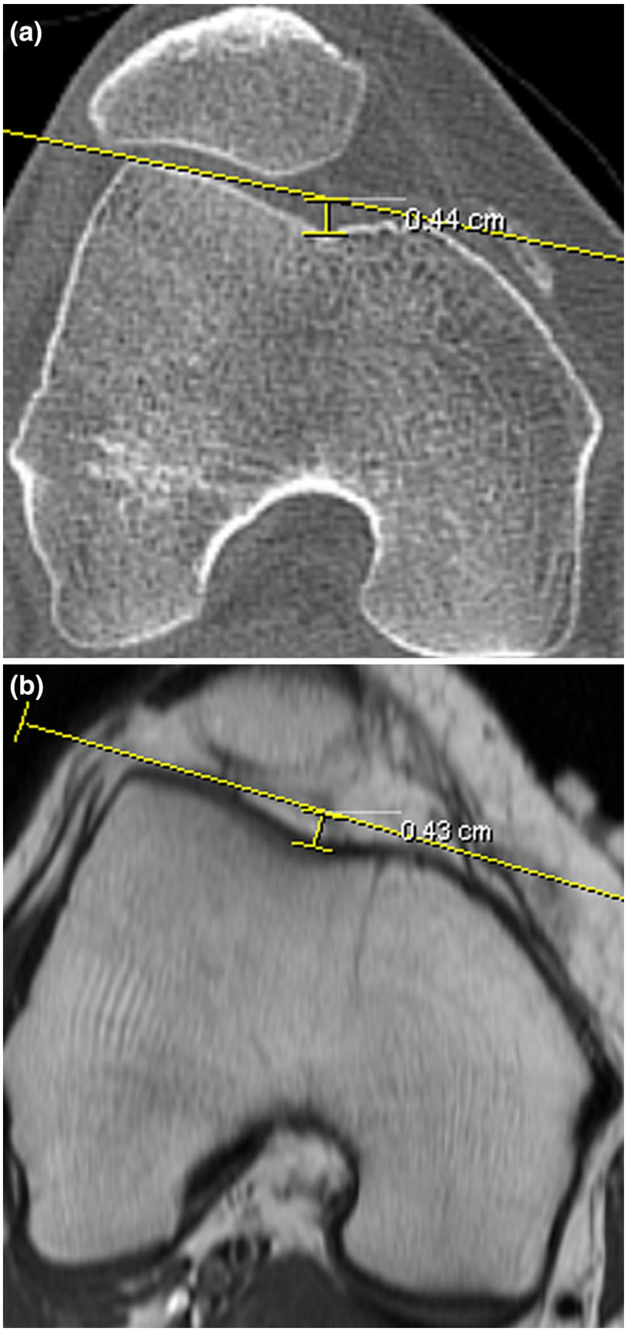


Fig. 3 Axial section of knee joint on CT (**a**) and non-fat-suppressed proton density MRI (**b**) showing the trochlear depth measurement. TD was calculated on axial scans on both CT and MRI as the perpendicular distance between the deepest point on the trochlear sulcus and the line joining the superior point of medial and lateral trochlear facets

based on the absence or presence of the individual abnormality. For the cartilage abnormality of patella and trochlea, grading of 0, 1 and 2 was given for normal cartilage, low-grade cartilage abnormality (cartilage heterogeneity, surface irregularities, <50 % cartilage thickness loss) and high-grade cartilage abnormality (erosions, defects or fissures with more than 50 % cartilage thickness loss), respectively.

Statistical analysis

All data were stored on a spreadsheet (Excel 2007, Microsoft, Seattle, WA, USA), and analysis was performed using the SPSS software (version 18.0, SPSS Inc., Chicago, IL, USA). For the quantitative parameters, intra-class correlation coefficient (ICC) was used to evaluate inter-observer and inter-method reliability. Bland–Altman plot was used to depict the inter-method difference for all three variables. The TT–TG distance, TA and TD values of more than 15 mm and 144°, and <5 mm, were used as the cut-off points for abnormality (17), respectively, and two radiologists consensus reading was used to evaluate their association with soft tissue abnormalities of the patellofemoral joint. Chi-square test was used to assess the statistical significance of the qualitative variables. Level of significance was set as *p* value <0.05.

Results

The mean range (mean of ranges of all three readers) for TT–TG on CT and MRI is 9.3–23.0 and 9.4–19.7 mm, respectively. The mean range for TA on CT and MRI is 113°–172° and 112°–171°, respectively. The mean range for TD on CT and MRI is 0.5–10.1 and 0.8–9.2 mm, respectively.

Mean values of all readers for TT–TG distance (in mm), TD (in mm) and TA (in °) on both CT and MRI for all the three readers and ICC are shown in Table 1. For TT–TG distance, there was an excellent inter-observer reliability [ICC for MRI = 0.90 (0.83–0.95), and ICC for CT = 0.89 (0.82–0.94)] and inter-method reliability [ICC = 0.86 (0.71–0.93), mean difference = 0.6 mm]. For TA, there was an excellent inter-observer reliability [ICC for MRI = 0.95 (0.91–0.97), and ICC for CT = 0.89 (0.81–0.94)] and inter-method reliability [ICC = 0.89 (0.79–0.95), mean difference = 1.4°]. For TD, there was an excellent inter-observer reliability [ICC for MRI = 0.95 (0.92–0.98), and ICC for CT = 0.95 (0.92–0.98)] and inter-method reliability [ICC = 0.95 (0.90–0.97), with mean difference = 0.1 mm]. Bland–Altman plot shows the inter-method reliability for all the quantitative measurements (Fig. 4).

There was a significant association between increased TT–TG distance value on MR imaging and lateral facet patellar cartilage abnormality and joint effusion ($p < 0.05$). Seventeen of 32 cases had an abnormal TT–TG distance (>15 mm). Twelve of 17 cases of abnormal TT–TG distance had cartilage abnormality in the lateral patellar

Table 1 Inter-observer and inter-method reliability and mean values of TT–TG distance, TA and TD on CT and MRI

Modality	TT–TG (mean)	ICC for TT–TG (inter-observer)	TA (mean)	ICC for TA (inter-observer)	TD (mean)	ICC for TD (inter-observer)
CT	15.3 ± 3.0	0.89 (0.82–0.94)	148.5 ± 11.2	0.89 (0.81–0.94)	4.2 ± 1.8	0.95 (0.92–0.98)
MRI	14.7 ± 2.8	0.90 (0.83–0.95)	147.1 ± 11.2	0.95 (0.91–0.97)	4.3 ± 1.7	0.95 (0.92–0.98)
ICC (inter-method)	0.86 (0.7–0.93)		0.89 (0.79–0.95)		0.95 (0.90–0.97)	

The mean range (mean of ranges of all three readers) for TT–TG on CT and MRI is 9.3–23.0 and 9.4–19.7 mm, respectively. The mean range for TA on CT and MRI is 113°–172° and 112°–171°, respectively. The mean range for TD on CT and MRI is 0.5–10.1 and 0.8–9.2 mm, respectively

ICC intra-class coefficient, *TT–TG* tibial tuberosity–trochlear groove distance, *TA* trochlear angle, *TD* trochlear depth

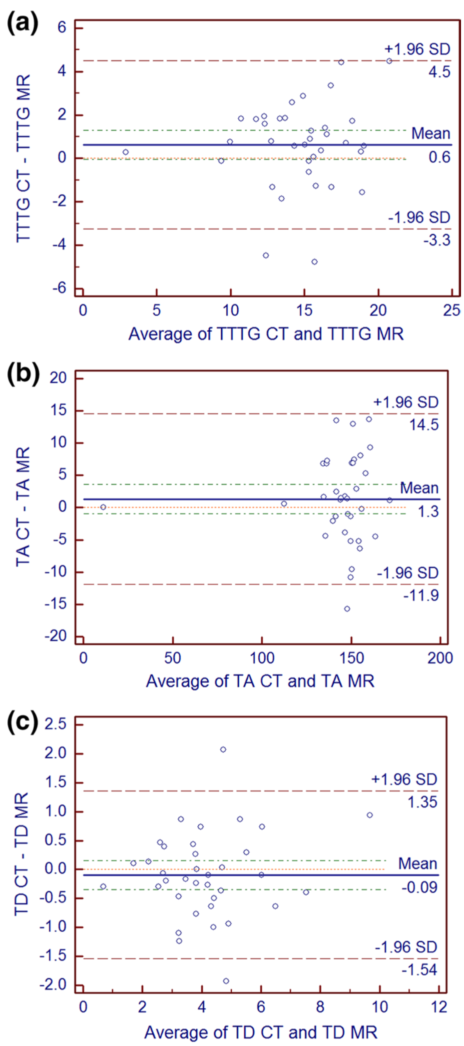


Fig. 4 Bland–Altman plot depicting inter-method reliability for **a** TT–TG on CT and MRI, **b** trochlear angle (TA) on CT and MRI and **c** trochlear depth (TD) on CT and MRI

facet (seven had low-grade and five had high-grade cartilage defect) (Figs. 5, 6). No other association was found between any other qualitative and quantitative variables.

Discussion

The most important findings of these study are excellent inter-observer and inter-method reliability of patellofemoral measurements on both CT and MRI, with TT–TG distance value being the most useful to correlate with lateral facet patellar cartilage abnormality and joint effusion. Many anatomical factors such as trochlear dysplasia, increased patellar height, patellar tilt/translation and tibial torsion predispose to patellofemoral instability [4, 11, 13]. Many of these measurements vary due to alterations in leg positioning and degree of knee flexion. One such measurement is patellar tilt which is calculated as the angle between the line joining the medial and lateral facets of the patella and the line tangent to the posterior femoral condyle, a method more analogous to the clinical examination. However, it may be difficult to measure the angle using this technique, as the two respective lines forming the angle are generally visualized on two different axial images because of the changing slope and size of the femoral condyles [7]. Measurements such as TA, TD and TT–TG distance are relatively independent of patient positioning. The information about their inter-observer reliability and direct effect on internal derangement of knee is limited [24]. The position of the tibial tubercle is crucial for the infero-lateral force vector of the patella. In a normal joint, the tibial tuberosity lies vertically under the femoral sulcus (within 1 cm), directing the force vector inferiorly during the knee bending. However, if there is excessive lateralization of the tibial tuberosity, the patella is prone to be pulled laterally during flexion. This excessive lateral displacement is thought to predispose to patellar chondrosis and friction-related knee fat pad oedema [7, 11].

Traditionally, CT imaging has been used to calculate TT–TG distance; however, Saudan and Fritschy [23] showed an inter-rater reliability of <60 % in TT–TG distance determination by this method. Additionally, CT imaging is unable to detect soft tissue abnormalities related to the patellofemoral instability, which may determine the treatment options. Furthermore, since the patellofemoral

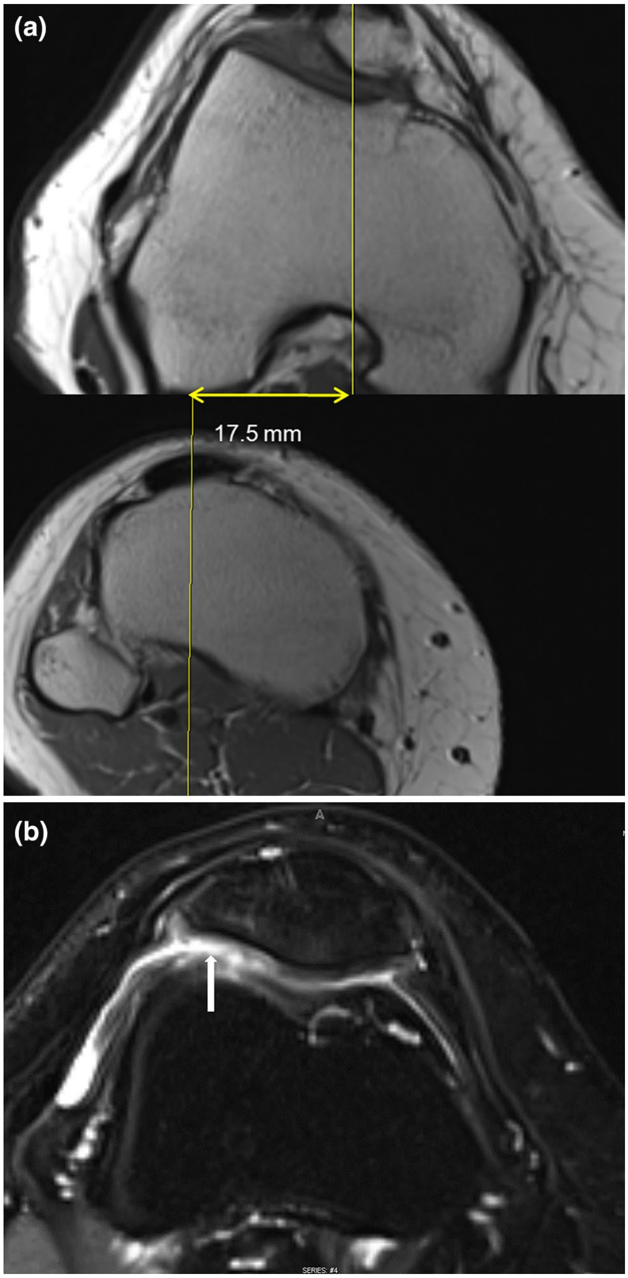


Fig. 5 Non-fat-suppressed proton density axial section (**a**) shows that an increased TT–TG distance is associated with the presence of patella lateral facet chondrosis (*arrow*) as seen on axial (**b**) fat-suppressed proton density sequence

pain syndromes are common in young patients, there is a radiation risk associated with CT examinations. It is therefore desirable to have a one-stop imaging technique which can determine the anatomical parameters related to patellofemoral joint as well as assess the associated internal derangement in the same setting.

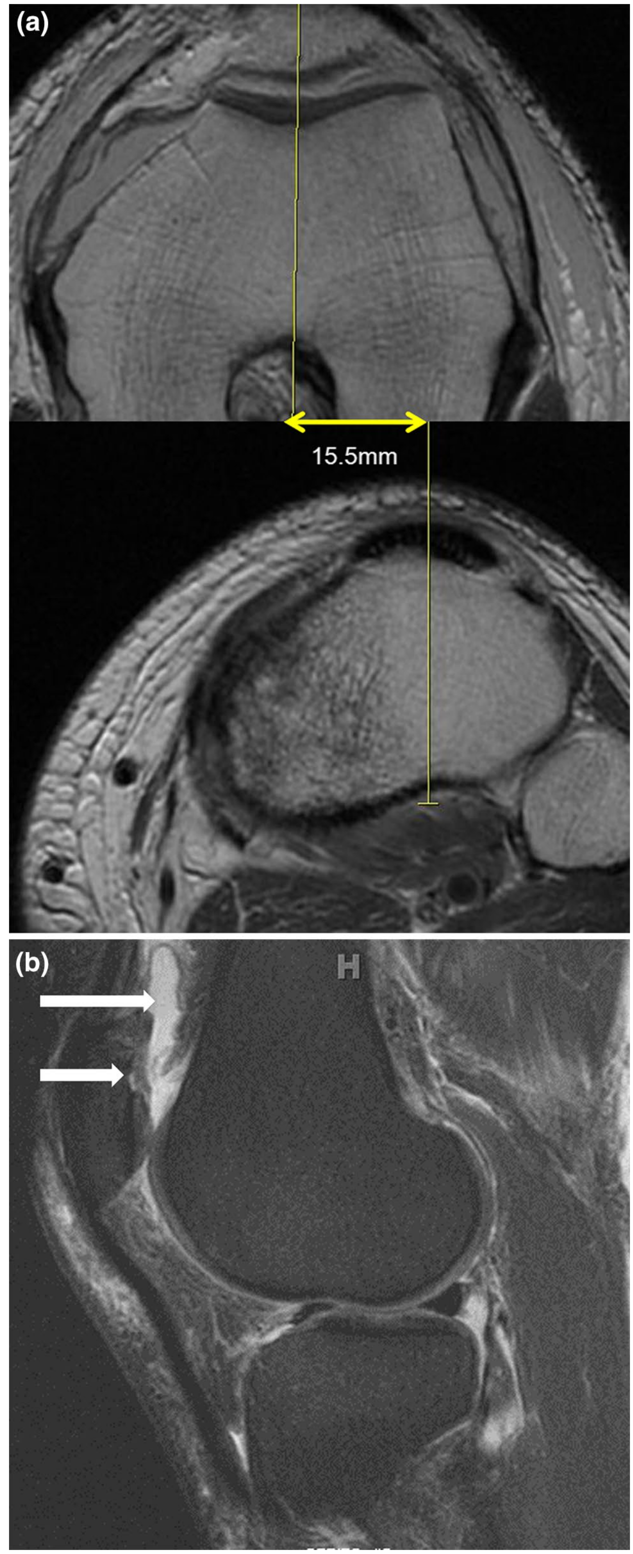


Fig. 6 Non-fat-suppressed proton density axial section (**a**) shows that an increased TT–TG distance is associated with the presence of patella lateral facet chondrosis (*large arrow*) and joint effusion (*small arrow*) as seen on sagittal (**b**) fat-suppressed proton density sequence

Our study showed that TT–TG distance, TA and TD can be calculated reliably on MR and additional CT scans are not required. Although Schoettle et al. [24] had determined that TT–TG distance can be calculated on MRI, in our study, we proved that not only TT–TG distance but also TA and TD can be calculated easily and reliably on MRI similar to CT imaging, as all these measurements have been shown to be important for diagnosing patellar instability [12]. Bony landmarks were used for the measurement purposes to avoid the variability related to the cartilage thickness [7]. For TD, the ICC values were similar for CT and MRI, and for other measurements, MRI in fact performed marginally better. The inter-method reliability was excellent for all measurements. These results solidify the concept of using MRI instead of CT for the anatomical measurements of TA, TD and TT–TG distance. For the qualitative analysis, TT–TG distance more than 15 mm, TA more than 144° and TD more than 5 mm were used as cut-off to assess their association with the soft tissue findings on MRI [7, 22, 30, 32]. Abnormal TT–TG distance indicating tibial tuberosity lateralization/transposition correlated with lateral facet patellar chondrosis and joint effusion was determined in our study [22]. These findings confirm that effusion is a good secondary sign of internal joint derangement and the abnormal lateralization of the patellar tendon/tibial tuberosity leads to an increased lateral pull of the quadriceps femoris muscle (vastus lateralis obliquus) on patella, potentiating patellofemoral joint derangement. MRI can prudently serve as one-stop modality for evaluation of these measurements as well as associated internal derangement findings.

MRI has several advantages over CT imaging for assessment and treatment of patellofemoral disorders. MRI offers better soft tissue contrast and excellent visualization of the articular cartilage. It is therefore helpful in planning for surgical procedures and quadriceps strengthening exercises aimed at reducing compressive stresses in the patellofemoral joint by visualizing the defective cartilaginous surfaces, which may need to be offloaded [20]. In patients with severe trochlear dysplasia, assessment of the cartilage is pivotal as pre-operative cartilaginous degeneration has been associated with inferior results. MRI is therefore helpful in patient selection and pre-operative planning for trochleoplasty [25, 31]. MRI also minimizes exposure to radiation and as shown by our results, and it is more reliable to measure TT–TG distance using MRI, since the centre of the patella tendon is used as opposed to the most anterior part of the tibial tuberosity as on CT, which is a more anatomical measurement of the TT–TG distance and better represents the direction of forces of the patellar tendon [15]. We therefore used this reference point for the centre of the patellar tendon insertion as was defined by Wittstein et al. [32] and Schoettle et al. [24]. Our study demonstrates that either MRI or CT can be used for the measurement of TT–TG distance, TA and TD with excellent inter-observer reliability. There is an association between increased TT–TG distance with lateral facet patellar cartilage abnormality and joint effusion. Hence, it is important to report TT–TG distance in reports of MRI performed for patellar instability cases.

There are some limitations to our study. It was a retrospective study, and we did not obtain clinical correlations. However, identification of joint effusion and articular cartilage damage is a very objective finding confirming the presence of internal derangement of the patellofemoral joint. Correlation with patellar height indices was also not obtained, although it seems to vary with degree of knee flexion. In future, it might be worthwhile to assess the TT–TG distance on kinematic MRI to exploit these dynamic patellofemoral relationships by imaging patients in varying degrees of flexion and extension and correlating them clinically. It is possible that patients with and without patellofemoral joint disorders were included and that both normal and abnormal values of the estimated measures were rated in CT and MRIs. Additionally, wide age range is studied here. However, we tried to capture a consecutive series of subjects from a 29-month period who both had CT and MRI of the knee without local surgery or hardware to minimize selection bias. Employing uniform cut-off values, a blinded reading was taken in all cases. To summarize, TT–TG distance should be reported in patellofemoral pain syndrome patients and MRI measurement suffices for the above purpose.

Conclusion

Quantitative trochlear parameters (TT–TG, TA and TD) can be reliably calculated on CT and MRI, and abnormal TT–TG distance is the most useful measurement among various static MR imaging parameters to correlate with patellar chondrosis and joint effusion.

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Conflict of interest The other authors report no conflicts of interest.

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